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WHAT DO WE KNOW ABOUT THE EXPLOSIBILITY OF COAL DUST IN MINES

BY

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WHAT DO WE KNOW ABOUT THE EXPLOSIBILITY OF COAL DUST IN MINES? [1]

By H. P. Greenwald[2]

INTRODUCTION

The Bureau of Mines has been conducting experiments on the explosibility of coal-dust in the experimental mine for more than 17 years. The results have been published from time to time[3], and a forthcoming technical paper[4] will summarize the results and discuss them in some detail. The present paper will be limited to a statement of the more important facts that these researches have discovered.

EXPLOSIBILITY OF COAL-DUST AND MEANS OF PREVENTING EXPLOSIONS

It is known that coal-dust is explosive only when raised as a cloud in air, and that a certain minimum concentration in the cloud must be obtained or exceeded before flame will pass through the cloud. There is almost everywhere in a coal mine ample dust deposits from which if untreated the coal dust clouds necessary to obtain a coal dust explosion can be formed, and the means of forming and igniting them are present only too frequently.

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[3] Rice, G. S., Jones, L. M., Clement, J. K., and Egy, W. L., First Series of Coal-Dust Explosion Tests in the Experimental Mine: Bull. 56, Bureau of Mines, 1913, 115 pp.
Rice, G. S., Jones, L. M., Egy, W. L., and Greenwald, H. P., Coal-Dust Explosion Tests in the Experimental Mine, 1913 to 1918, Inclusive: Bull. 167, Bureau of Mines, 1922, 639 pp.
Rice, G. S., Paul, J. W., and Greenwald, H. P., Coal-Dust Explosion Tests in the Experimental Mines, 1919 to 1924, Inclusive: Bull. 268, Bureau of Mines, 1927, 176 pp.
Rice, G. S., Greenwald, H. P., and Howarth, H. C., Coal-Dust Explosion Tests in the Experimental Mine, January, 1925 to March, 1928 (in preparation).

[4] Rice, G. S., and Greenwald, H. P., Factors Affecting the Explosibility of Dust in Coal Mines: A Summary of Results of Investigations in the Experimental Mine (in preparation).

Before examining the explosibility of coal-dust some measure must be adopted for the property which is so named. It has been found best to consider explosibility proportional to the amount of incombustible material required in a coal-dust rock-dust mixture to prevent propagation of flame through that mixture, provided that it is dry enough to form a dust cloud readily. This rules out mixtures containing water, which will be considered later. After adopting this standard it is necessary to select a standard rock-dust or to investigate the relative effectiveness of several rock-dusts. The latter course has been followed to some extent with finely sized dry dust, and the following factors have been found: (1) The effectiveness of rock-dust is independent of chemical composition, provided that there is not more than 2 per cent combustible material in it. Thus, dusts made from limestone, soapstone, adobe, shale, and gypsum are all equally effective. (2) Approximately equal weights of different rock-dusts are required, irrespective of their specific gravities. The effectiveness of diatomite-dust has been compared with that of shale-dust in gallery tests, and it has been found that only slightly less weight of the former was required, despite the fact that its volume per unit weight was 4 to 6 times that of the shale. (3) The size of the rock-dust is more important than either its composition or specific gravity, provided of course that it contains no combustible material.

Two sizes of rock-dust were used in early work at the experimental mine. The first was called pulverized dust, of which about 98 per cent would pass a 200-mesh sieve; the second was called 20-mesh dust, of which about 95 per cent would pass 20-mesh sieve, and 35 to 40 per cent would pass a 200-mesh sieve. It was found that the finer dust was the more effective, but that the difference could be offset by using 3 to 5 per cent more of the coarser dust. When rock-dusting specifications were drawn, it was stated that the dust used should be ground so that all would pass a 20-mesh sieve and 50 per cent would pass a 200-mesh sieve. This was considered to be the best compromise between effectiveness and cost, which mounts rapidly with fine grinding. This specification was also adopted by the American Engineering Standards Committee and it is the British standard size for stone-dust as well.

FACTORS INFLUENCING EXPLOSIBILITY OF COAL-DUST

Experimental evidence may be said to show that the explosibility of a given coal-dust is not constant even when present in the proper amount in a given mine passageway. The explosibility is influenced by the following factors:

1. Size of the dust.
2. Composition of the dust.
3. Presence of fire damp in the air.
4. Quantity of coal dust present
5. Manner in which the dust is distributed.
6. Characteristics of the igniting source.
7. Surrounding conditions.

1. Size of dust.- Mine dust is defined as all material which will pass a 20-mesh sieve. This specification was first made in 1909 following certain gallery tests and was later supported by tests in the experimental mine in which the addition of material coarser than 20-mesh did not change the quantity of rock-dust required to prevent propagation of flame through coal-dust finer than 20 mesh. It is assumed that in general the coarser material does not take part in an explosion when an ample amount of finer material is present. An exception might occur in explosions developing so much violence as to abrade coal from the ribs and cause a general degradation in the size of the dust. The question of the size of dust, however, can not be dismissed with the statement that all must pass a 20-mesh sieve. Further subdivision has been found necessary, and dusts are classified according to the amount of minus 200-mesh material which they contain. Tests have been made in the experimental mine with dusts having 10, 20, 40, and 85 per cent through 200 mesh. The last is commonly called pulverized dust. The dusts found in many mines have been examined in connection with explosion-hazard investigations, and it has been found that mine dusts usually have an average of 15 to 25 per cent of dust that will pass a 200-mesh sieve. Road dusts are coarser and rib dusts much finer than this average. The road dusts greatly outweigh the rib dusts in quantity. As a result of this, dust having 20 per cent through 200 mesh has been most used in tests of coals received from producing mines in various parts of the country.

2. Composition of the dust.- In a broad sense composition should cover variations in the moisture, volatile matter, and ash content of the dust. However, the moisture and ash of coal can not be distinguished from the moisture and ash of admixed inert material either in a mine dust or in a mixture prepared for test in the experimental mine. It is customary to group the incombustible portion of the coal with admixed combustible, and although the effect of the two is probably not proportional to their relative weights, the quantity of incombustible in the coal itself is relatively so small in most cases that any difference in action may be ignored. Study of the effect of varying composition then resolved itself into a study of the effect of variations in volatile matter content, and these are best expressed on a moisture and ash-free basis. They are the same as the ratio of volatile matter to total combustible, which varies from 0.05 for anthracites to 0.50 for subbituminous coals. In order to determine the matter experimentally, it was necessary to specify the size of dust used and the method under which the dusts should be tested. Consideration is given here only to the relative explosibility of dust having 20 per cent through 200 mesh when subjected to the standard propagation test in the experimental mine.

Details of this test method are given in Bureau of Mines Bulletin 268, page 36. Briefly, the dust mixture under test is subjected to the explosion developed by 100 pounds of pulverized Pittsburgh coal-dust when ignited by a blow-out shot of 4 pounds of black blasting powder. Dusts of the size specified, prepared from 29 different coals, have been subjected to this test. The conclusions drawn are summarized in the following table which gives the proportion of incombustible material required in mixtures of coal and rock dust to prevent propagation of an explosion through them under the test conditions.

Incombustible required to prevent propagation of an explosion through 20 per cent 200-mesh dusts of various coals

Volatile ratio of coal	Incombustible required, per cent.	Volatile ratio of coal	Incombustible required, per cent
0.14	14	0.23	60
0.15	20	0.25	61
0.16	25	0.30	61
0.17	31	0.35	61
0.18	36	0.40	61
0.19	42	0.43	63
0.20	47	0.46	66
0.21	53	0.49	69
0.22	58		

Explosibility increases rapidly between ratios 0.14 and 0.25, remains constant between ratios 0.25 and 0.40, and then increases slowly. As most of the coals now being mined in the eastern part of the United States have volatile ratios lying between 0.25 and 0.40, it follows that 61 per cent incombustible is required in a majority of the mines when no gas is present.

3. Fire damp in the air.- The presence of fire damp in air increases the explosibility of a coal-dust cloud raised in that air. It has been found from many experiments that there is a definite rule connecting this increase in explosibility with the explosibility of the dust when no fire damp is present and the lower limit of explosibility of fire damp air mixtures with no dust present. The limit of explosibility of the dust with no fire damp present must be known to apply the rule which reads: Subtract the no-gas limit from 100 and divide by 5. The result is the percentage of incombustible required to offset each 1 per cent of fire damp in the air current. Thus, if a coal requires 60 per cent incombustible with no fire damp present, $\frac{100-60}{5} = 8$ per cent additional incombustible is needed for each 1 per cent of fire damp in the air current. If the requirement was only 30 per cent with no fire damp, then each 1 per cent would require $\frac{100-30}{5} = 14$ per cent additional incombustible material. Under this rule 100 per cent incombustible must be present with 5 per cent fire damp, which is approximately the lower limit of inflammability of fire damp-air mixtures when strong sources of ignition are used.

4. Quantity of Coal Dust.- We do not know precisely how small an amount of coal dust already in suspension in air would propagate an explosion, but as little as 4.8 ounces of coal dust per linear foot of entry, when distributed on cross-shelves and side shelves, has done so. To produce maximum violent effects, the quantity of coal dust per unit of entry or room space varies with the size of dust particles and the stage of the explosion at the particular place in the mine. An excess of coal dust will tend to absorb heat and lessen violence but will not prevent flame from propagating with disastrous results.

5. Distribution of dust.- Mine dust is usually found on every point in the entry perimeter, on the floor, ribs, timbers, and adhering to the roof. When it is dislodged from elevated surfaces, gravity aids in forming a cloud; when raised from the floor, gravity opposes the formation of a dust cloud. In this manner the explosibility of mine dust is influenced by its original place along the perimeter of the entry. The effect on explosibility was demonstrated in the early work in the experimental mine. At first, dust was placed only on longitudinal side shelves and on the floor. Later, cross-shelves were installed near the roof at 10-foot intervals and part of the dust was placed on them. Under these conditions the amount of rock-dust required to prevent propagation of an explosion was increased 10 to 15 per cent. In operating mines the problem is complicated by the fact that dusts in the different places differ in composition, size and quantity, and the effect of simultaneous changes in these can not be predicted. A great deal of experimental work must be done on this problem, which up to the present time has received scant attention because of other work. A few isolated results indicate what may be expected from a careful study. It was found that an explosion could propagate through a strip of pure coal-dust 5 feet wide placed on the floor when the side-shelves were loaded with four times as much pure rock-dust. Where such a strip of coal-dust exists, because of spillage on haulageways, it must receive separate treatment except possibly where large quantities of rock-dust are present on overhead cross-timbers.

In another set of experiments it was found that a mixture containing 40 per cent of shale placed only on the floor would not propagate an explosion, nor would a mixture containing 65 per cent shale propagate an explosion when placed on cross and side shelves only. But propagation was obtained easily when both mixtures were placed simultaneously. To prevent propagation it was necessary to increase the shale content of the floor dust 5 per cent or that of the shelf dust 15 per cent. The only outstanding point in all the fragmentary work is that in no case was it necessary to have as high a percentage of rock-dust on the floor as on the ribs and roof. If fully substantiated this will be of great practical value, because in a given time the floor of a mine entry always receives the greatest contamination from coal-dust.

6. Source of ignition.- The term "source of ignition" is used to designate any arrangement of gas, explosives, or coal-dust either singly or in combination by means of which an explosion is projected into a dust mixture to determine the ability of that mixture to extinguish the explosion. While an unlimited number of sources can be devised under this definition, good judgment limits them to such as may be found in commercial mines. It has been found that the explosibility of coal-dust varies with the strength of the source of ignition. For example: the amount of rock dust required to prevent propagation of flame directly from a blow-out shot of 4 pounds of black blasting powder has been determined for a number of coals. This charge was selected as one not likely to be exceeded where coal is undercut. When 100 pounds of pure coal-dust is added in front of this blow-out shot, the arrangement becomes a standard propagation test, the igniting source is much stronger, and the amount of rock-dust required to prevent propagation is considerably increased. If a 50-foot zone of a 10 per cent natural gas-air mixture

ignited at the closed end is substituted for the cannon shot and coal-dust, a still stronger source is obtained and the amount of rock-dust required is increased again. There is, of course, a limit to this process at some point, but where this limit lies can not be said. A study of sources of ignition would require determination of (a) their dust-raising power and (b) their igniting power. Here again is a problem which has received scant attention, yet our knowledge of the explosibility of coal-dust is not complete until it is solved.

Practical applications will be possible only as the sources commonly found in mines are known. Fifteen years ago black blasting powder was responsible for many mine explosions. Blasting methods have been improved since that time and today electric arcs are the initiators of a majority of the mine explosions in this country. More commonly the arc or spark ignites a gas accumulation, and the gas explosion raises and ignites dust. There are, however, an alarming number of explosions from the ignition of dust clouds by electric arcs as an immediate sequel of haulage accidents which have occurred on pure intake air and in one or two cases close to the mine mouth. Quantitative studies of the initiation of dust explosions by gas explosions and by electric arcs have not yet been made in the experimental mine. A study of gas explosions opens a wide field of experimentation, because accumulations in mines are more likely to be nonuniform or stratified owing to the manner in which and the conditions under which the gas is liberated. Again, even with a uniform mixture the nature of a gas explosion will vary with the point at which the body is ignited and the degree of confinement to which it is subjected. It is evident, however, that more precise data on the initiation of coal-dust explosions must await a better knowledge of gas explosions in mines; it is also evident that thorough ventilation of gassy mines removes one of the principal means by which coal-dust explosions are started.

7. Surrounding conditions.- The factor of surrounding conditions includes all the physical influences, not a part of preceding factors, under which an explosion occurs. These conditions may be divided into (a) openings from or enlargements of the passageway in which the explosion is traveling, and (b) constrictions of or obstruction in this passageway. The former allow release of pressure and the latter cause retention of pressure. Intersection or branching of passageways belongs in the first, and bends in passageways belong in the second division. The effect of release of pressure ahead of an explosion is to cause an acceleration of the flame speed as it approaches the point of release. Release of pressure behind an explosion greatly retards the progress of the flame and in extreme cases may extinguish it. These phenomena have been demonstrated both in the experimental mine and in the gallery at Eskmeals, England, where a series of experiments were conducted on them. The results so far have been qualitative only.

EFFECT OF WATER ON EXPLOSIBILITY OF COAL-DUST

The foregoing items summarize briefly our knowledge of the explosibility of dry dust mixtures. Wet dusts can not be classified with dry dusts because of the tendency of the particles to cling together, making the formation of a dust cloud more difficult. Experiments have shown that the effectiveness of water in preventing scattering of dust is the only thing that can justify its use; at the working face there is certainly ample place for it. On the other hand, the use of water to render coal-dust nonexplosive in mine passageways has been a flat failure, and there is experimental evidence to show that it can not succeed with bituminous coals. Tests were made in 1925 of mixtures of four Utah coal-dusts and water. It was found in the course of this investigation that 20 per cent water was as much as these dusts (size 20 per cent through 200 mesh) would retain; if more was added it sank through the dust and drained away, confirming in general earlier similar tests on Pittsburgh bed coal-dust. Mixtures of two of the coals containing 20 per cent water propagated explosions under standard propagation test conditions. A similar mixture of the third coal was subjected to a gas explosion and also propagated flame throughout the test zone. These tests leave little doubt concerning the explosibility of wet bituminous coal-dusts. It is true that such wet dusts are raised into the air from the floor only with considerable difficulty, but they are dislodged from higher surfaces or timbers with ease, and when formed in a cloud by any means, they ignite and propagate flame despite the presence of the water.

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